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Sanitary Landfill Leachate Controls at
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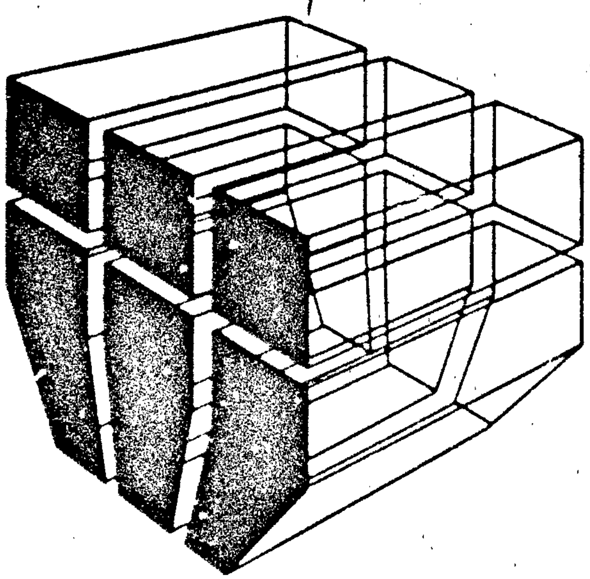
# Sanitary Landfill Leachate Recycle and Environmental Problems at Selected Army Landfills: Lessons Learned



by
Stephen W. Maloney



This report provides information on (1) experience with leachate recycling—a method of treating leachate from landfills that will remove various leachate components, and (2) lessons learned from ongoing investigations at Army installations experiencing problems associated with landfills.

Advantages of leachate recycling are its ability to increase the rate of stabilization of biodegradable organic matter and its potential to remove some heavy metals and organics from the leachate. Its major disadvantage is its potential to contribute to surface- or groundwater pollution under certain conditions.

Installations considering use of leachate recycling should incorporate appropriate modifications into the landfill design and must select the landfill site carefully. They should also be aware of lessons learned from problem situations at other installations, and carefully coordinate planning with all appropriate regulating authorities. They should also use the technical expertise available from other Army agencies to assist with developing plans for the recycling option.



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# FOREWORD

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Mr. Robert E. Riggins is Acting Chief of USA-CERL-EN. COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

## CONTENTS

# SANITARY LANDFILL LEACHATE RECYCLE AND ENVIRONMENTAL PROBLEMS AT SELECTED ARMY LANDFILLS: LESSONS LEARNED

## 1 INTRODUCTION

### Background

Before World War II, the Army disposed of refuse on land (open dumps) in remote areas of an installation and periodically burned the combustible materials. The Army adopted sanitary landfilling as a solid waste disposal practice in 1942, when published instructions recommended that refuse to be compacted in trenches and covered daily with soil. In 1946, the Army published Technical Manual (TM) 5-634,[1] which provided specific guidance on refuse collection and disposal. At that time, the primary objectives were to reduce garbage odors and blowing litter and to control insects and rodents. Leachate, which results from water discharge through the solid waste regardless of whether it's buried or not, was not recognized as a major problem at that time.

Leachate forms in sanitary landfills when water passes through the landfill and leaches breakdown products and materials that resist breakdown into the aqueous phase. If not contained and/or treated, these materials can threaten surface- or groundwater. Modern landfills have liners to contain the leachate, but ultimately it must be collected for treatment.

Percolating water and resultant leachate also have positive effects on the operation of a landfill. A natural by-product of anaerobic microbial activity in landfills is methane gas; the anaerobic process requires water to maintain optimal conditions. Degradation of the deposited refuse reduces the pile volume, and can lead to surface subsidence. Thus, when planning to reuse the land after the sanitary landfill is closed, enough time must be allowed for the subsidence to reach completion (i.e., the organic matter must become stabilized). The cessation of methane production in a landfill is often used as an indicator that the landfill has been stabilized.

Recycling* the leachate continuously seeds the landfill with microorganisms acclimated to the substrate and maintains sufficient moisture to encourage microbial growth; this stabilizes landfills more quickly. Furthermore, recycling may reduce the degree and amount of treatment required. Thus, recycle appeared to be a way to solve leachate disposal problems and accelerate landfill stabilization. However, many materials placed in sanitary landfills resist microbial degradation. These include industrial solvents such as trichloroethylene (TCE), which occurs in household degreasers, and heavy metals resulting from corrosion of solid waste. Increasing the hydraulic load on a landfill through leachate recycle increases the possibility of these materials being transferred into the groundwater. Thus, there is a tradeoff between increased potential for groundwater contamination and more rapid landfill stabilization (reducing the stabilization period from 20 years to a few years).

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[1]Technical Manual (TM) 5-634, *Refuse Collection and Disposal: Repairs and Utilities* (Department of the Army [DA], 1946).

*Collecting landfill leachate and pumping it back to the top of the landfill.

The change from open dumps to landfills solved one problem, but did not address the leachate problem. The effect of open dumps on subsurface water quality is essentially unknown, because they were confined to isolated areas and posed such other obvious problems that subsurface problems were not investigated. Thus, solid waste disposal is evolving from a period of concern for surface problems to one of concern for leachate control and treatment, and most currently to the area of specific leachate components (i.e., those classified as hazardous waste). Even sanitary landfills can contain large quantities of hazardous waste, because household items such as oven cleaners contain industrial solvents and because the classification of "hazardous" has only recently been applied to many materials that may have been disposed of in sanitary landfills. To properly review the potential utility of landfill leachate recycle at an Army installation, the Facilities Engineer must be aware of the lessons learned about the appropriate design and operation considerations for implementing this technology. The information presented in this report underscores the successes and shortcomings of leachate recycle.

## Objectives

The objectives of this report are to (1) summarize experience with leachate recycle and familiarize Facilities Engineers with its advantages, (2) discuss methods to enhance the effectiveness of leachate recycle, (3) outline potential problems associated with leachate recycle to explain why retrofitting this technology is only appropriate under highly controlled conditions, (4) briefly discuss design considerations for leachate recycle, and (5) present lessons learned from recent landfill investigations on Army installations.

## Approach

The following steps used to develop the information presented in this report are based on experience gained in the private sector at both experimental and full-scale operating facilities.

1. The literature was reviewed to obtain information on the theory and practice of leachate recycle, experience with using leachate recycle to remove biodegradable organics and heavy metals, and methods to enhance the effectiveness of leachate recycle.

2. Potential problems with leachate recycle were outlined.

3. Design considerations for incorporating leachate recycle into new landfills were examined.

4. Army installations undergoing landfill investigations were visited to determine lessons learned which could be used as guidance for Facilities Engineers on design and operations considerations for leachate recycle.

## Users

The techniques described in this report apply to all fixed Army installations that have operated, are operating, or will operate a sanitary landfill.

## Mode of Technology Transfer

It is recommended that the information in this report be used to revise Army Technical Manuals (TMs) on solid waste disposal, specifically TM 5-634, *Refuse Collection and Disposal: Repairs and Utilities* and TM 5-814-5, *Sanitary Landfill*[2].

[2]TM 5-814-5, *Sanitary Landfill* (DA, 1983).

## 2 LITERATURE REVIEW

Collecting and recycling leachate at the landfill site is a potentially useful treatment for removing various leachate components. Recycle appears to reduce the time needed to stabilize biodegradable organic matter, and more rapid stabilization allows earlier reuse of the land. Leachate recycle appears to be one of the least expensive methods for partial treatment and disposal of leachate at properly designed and operated landfill sites. The mechanisms involved in stabilizing biodegradable organic matter are both biological and physical-chemical. The biological reactions are basically anaerobic; however, aerobic conditions prevail at the beginning of landfill use and may continue in some sections after organic stabilization.

Leachate recycle enhances landfill stabilization rate, partial leachate treatment, and leachate disposal by providing the following:

1. Homogeneity of moisture for a better biochemical environment

2. Loss of leachate volume by evapotranspiration at the surface

3. Reduction in discharge of organic matter and heavy metals to the environment

4. Increased rate of gas production per unit area

5. Removal of some organics, heavy metals, and other contaminants by adsorption and precipitation

6. Potentially fewer leachate management problems with respect to external treatment and disposal due to reduced volumes of total leachate and lower concentrations of some contaminants in leachate that cannot be recycled.

Pohland and Harper[3] have compiled information on the results of pilot-scale and full-scale recycling studies. Most of their information on full-scale recycling refers to sites in other countries; however, most of the pilot-scale investigations refer to sites in the United States. Pilot-scale investigations involved either daily or weekly recycling of leachate with or without pH adjustment and nutrient and microbial seed addition. pH adjustment was found to be an important factor in accelerating the organic matter "stabilization" process, maximizing the rate of methane formation and optimizing the methane composition of gas production. Nutrient addition along with microbial seeding did not appear to increase the removal of contaminants.

### Characteristics of the Leachate Recycle Process

"Stabilization" of a landfill refers to the process by which the biodegradable organic material within the landfill is microbially decomposed to methane, carbon dioxide, water, and refractory and other organic materials. The process is essentially the same as anaerobic sludge digestion. Pohland, et al.,[4] described the stabilization process

[3] F. G. Pohland and S. R. Harper, *Critical Review and Summary of Leachate and Gas Production from Landfills*, Draft Report (Hazardous Waste Environmental Research Laboratory, U.S. Environmental Protection Agency [USEPA], 1985).

[4] F. G. Pohland, J. T. Dertian, and S. B. Ghosh, "Leachate and Gas Quality Changes During Landfill Stabilization of Municipal Refuse," In: *Proceedings of Third International Symposium on Anaerobic Digestion* (1983).

as occurring in five stages. The first phase is the initial adjustment phase when the moisture fills the voids in the wastes. Once sufficient moisture accumulates, a viable microbial community develops, which begins the stabilization process. The second phase is a transition phase during which the refuse components begin to become soluble in the liquid. The initially oxic system becomes anoxic. Volatile organic acids are first found in the leachate during this phrase.

Volatile organic fatty acids form during the third phase, and the waste goes through hydrolysis and fermentation processes. The leachate pH decreases, which may lead to increased mobility of some heavy metals. The formation of metal-organic complexes, which may occur throughout the process, may be particularly enhanced during this phase. Microorganisms use the released nutrients.

The fourth phase is fermentation-methane production; here, microbes convert the volatile organic fatty acids to methane and carbon dioxide. A bicarbonate buffering system develops that minimizes further lowering of the pH. Redox potential is low at this stage, and both gas production and leachate pH increase. The final phase is landfill maturation. As the rest of the degradable organic matter is used up, the microbial processes become dormant and gas production decreases to a minimum; oxic conditions may then develop. The refractory organics (humic materials) may complex with heavy metals in the leachate, decreasing the heavy metals concentration.

At a typical landfill, moisture may be added by precipitation, which percolates through the surface cover or enters during the filling, and by groundwater infiltration. In some landfills, moisture is obtained from the disposed materials and can also be formed from the biological decomposition of materials within the landfill. However, leachate generally does not form until the waste's moisture content exceeds the field capacity. (Field capacity moisture content is defined as moisture held in a medium after it is saturated and allowed to drain under gravity for 24 hours.) However, it is possible for localized areas of a landfill to reach field capacity and begin to generate leachate while the moisture content of other parts of the landfill is still below field capacity.

Leachate recycle would be expected to help stabilize biodegradable organic matter, because continued addition of moisture would maintain a more uniformly moist anaerobic condition more conducive to microorganism growth. The literature often states that contaminant transport within, and therefore out of, a landfill depends on the landfill having enough moisture to exceed its field capacity. However, this is not an accurate description of the situation because of the presence of localized areas where the field capacity may be exceeded. Furthermore, contaminant transport, which can lead to groundwater contamination, can occur under unsaturated flow conditions without the landfill's ever achieving field capacity.

## Chemical Characterization of Landfill Leachate

While landfill stabilization would not occur in distinct, discrete phases as described above, this sequence of events is expected to occur. However, the time period over which stabilization occurs is site-specific. The stages of organic stabilization can be tracked by physical, chemical, and biological analysis of the leachate. For example, the acid formation and fermentation stages can be traced by pH and redox potential measurements. Changes in 5-day biochemical oxygen demand ($BOD_5$) and chemical oxygen demand (COD) and their ratios can describe the progress of biodegradation. With the decomposition of biodegradable organic matter, the percentage of the organic matter in refractory forms increases, so the $BOD_5$-to-COD ratio decreases. Lu, et al.,[5] suggested that a first-order equation can be used to describe the relationship between landfill age and the concentrations of certain contaminants such as $BOD_5$, total dissolved solids (TDS), total organic carbon (TOC), and chromium in the leachate.

Addition of water beyond field capacity tends to dilute the leachate. However, while the concentration of the parameters may be diluted, the total mass of any contaminant passing through would not.

Table 1 summarizes the ranges of concentrations of a variety of biological, physical, and chemical characteristics of landfill leachate as reported by various investigators. "Typical" concentration ranges were determined based on data taken from Lu's[6] literature review (Table 1). For the current study, the "typical" concentration range has been defined as the range in which more than 70 percent of the values reported by Lu fell. While the data presented in Table 1 were from a variety of studies of several different landfill and test systems, and represented leachate samples from landfills of various ages, the ranges indicate the approximate concentrations and variety of concentrations that may be found. The data highlight the site-specific nature of leachate composition. The Keenan, et al.,[7] study (data included in Table 1) measured organic, inorganic, and heavy metal characteristics in leachate from a 50-acre sanitary landfill in southeastern Pennsylvania over 3 years (not believed to be the first 3 years of leachate production). The concentrations of many of the constituents evaluated, including ammonia, chloride, chromium, hardness, Kieldahl nitrogen, magnesium, and potassium varied widely with time during the first year of the study. Variability in the concentrations seemed to decrease during the second and third years of study; however, variability in the concentrations of other constituents, such as sulfate, was higher during the second or third years of monitoring.

Keenan, et al., reported that the concentration of ammonia in the leachate formed at the landfill was about 2000 mg N/L at the beginning of their study (the upper end of the range shown in Table 1) and varied greatly during the first year. Without recycle, the concentration of ammonia in the leachate was an average of 60 to 70 percent less than the initial concentration for the next 2 years; based on the coefficients of variation, the variability was considerably less. Chain and DeWalle[8] described the characteristics of leachate from several bench-, pilot- and full-scale studies. The ranges of the concentrations they reported (included in Table 1) also varied greatly.

The data presented in Table 1 were from studies conducted in different areas of the United States under different climatic conditions. For example, these studies refer to sites in Ohio, Pennsylvania, Wisconsin, Illinois, California, and Georgia. Since these

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[5]J. C. Lu, R. D. Morrison, and R. J. Stearns, "Leachate Production and Management From Municipal Landfills," In: *Proceedings of Seventh Annual Research Symposium, Municipal Solid Waste: Land Disposal*, EPA-600/9-31-002a (USEPA, 1981).

[6]J. C. Lu, B. Eichenberger, R. J. Sterns, and L. Melnyk, *Production and Management of Leachate From Municipal Landfills: Summary and Assessment*, EPA-600/2-84-092 (USEPA MERL, 1984).

[7]J. D. Keenan, R. L. Steiner, and A. A. Fungaroli, "Chemical-Physical Leachate Treatment," *Journ. Env. Eng. Div. ASCE*, Vol 109, No. 6 (1983), p 1371.

[8]E. S. Chain and F. B. DeWalle, *Evaluation of Leachate Treatment, Volume I: Characterization of Leachate*, EPA-600/2-77-186a (USEPA, 1977a).

## Table 1

### Concentration Ranges for Landfill Leachate Components

| Parameter (in mg/L except when noted otherwise) | Concentration range* | "Typical" concentration range** |
|---|---|---|
| $BOD_5$ | 4 - 57,700 | 1,000 - 30,000 |
| COD | 31 - 89,520 | 1,000 - 50,000 |
| TOC | 0 - 28,500 | 700 - 10,000 |
| Total volatile acids (as acetic acid) | 70 - 27,700 | --*** |
| $BOD_5$/COD (ratio) | 0.02 - 0.87 | 0.6 - 0.8 |
| COD/TOC (ratio) | 0.4 - 4.8 | 1 - 4 |
| Total Kjeldahl nitrogen (as N) | 7 - 1,970 | 10 - 500 |
| Nitrate (as N) | 0 - 51 | 0.1 - 10 |
| Ammonia (as N) | 0 - 1,966 | -- |
| Total phosphates | 0.2 - 130 | 0.5 - 50 |
| Orthophosphates | 0.2 - 130 | - |
| Total alkalinity (as $CaCO_3$) | 0 - 20,850 | 500 - 10,000 |
| Total hardness (as $CaCO_3$) | 0 - 22,800 | 500 - 10,000 |
| Total solids | 0 - 59,200 | 3,000 - 50,000 |
| Total dissolved solids | 584 - 44,900 | 1,000 - 20,000 |
| Specific conductance (µmhos/cm) | 1,400 - 17,100 | 2,000 - 8,000 |
| pH (units) | 3.7 - 8.8 | 5 - 7.5 |
| Calcium | 60 - 7,200 | 100 - 3,000 |
| Magnesium | 17 - 15,600 | 30 - 500 |
| Sodium | 0 - 7,700 | 200 - 1500 |
| Chloride | 4.7 - 4,816 | 100 - 2,000 |
| Sulfate | 10 - 3,240 | 10 - 1,000 |
| Chromium (total) | 0.02 - 18 | 0.05 - 1 |
| Cadmium | 0.03 - 17 | 0 - 0.1 |
| Copper | 0.005 - 9.9 | 0.02 - 1 |
| Lead | 0.001 - 2 | 0.1 - 1 |
| Nickel | 0.02 - 79 | 0.1 - 1 |
| Iron | 4 - 2,820 | 10 - 1,000 |
| Zinc | 0.06 - 370 | 0.5 - 30 |
| Methane gas (percent composition) | (up to 60%) | -- |
| Carbon dioxide (percent composition) | (up to 40%) | -- |

*Based on data of F. G. Pohland, *Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment*, EPA-600/2-75-043 (U.S. Environmental Protection Agency [USEPA], 1975); F. G. Pohland and S. R. Harper, *Critical Review and Summary of Leachate and Gas Production from Landfills*, Final Report (Hazardous Waste Environmental Research Laboratory, USEPA, 1985); J. D. Keenan, R. L. Steiner, and A. A. Fungaroli, "Chemical-Physical Leachate Treatment," *Journ. Env. Engr. Div. ASCE*, Vol 109, No. 6 (1983), p 1371; E. S. Chain and F. B. DeWalle, *Evaluation of Leachate Treatment, Volume I: Characterization of Leachate*, EPA-600/2-77-186a (USEPA, 1977a); W. J. Mikucki, E. D. Smith, R. Fileccia, J. Bandy, G. Gerdes, S. Kloster, G. Schanche, L. J. Benson, M. J. Staub, and M. A. Kamiya, *Characteristics, Control and Treatment of Leachate at Military Installations*, Interim Report N-97/ADA097035 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1981).

**Ranges in which 70 percent of the values reported by Lu (1984) fall.

***--Indicates no data presented by cited author.

leachates were not from the same type of landfill or lysimeter, it was difficult to draw any conclusions about the variation in leachate characteristics over a geographic region.

Mikucki, et al.,[9] compiled from the literature ranges of concentration for characteristics of landfill leachates (incorporated in Table 1). He compared the concentrations of constituents in raw domestic wastewater to those in the leachate of the 6-month-old Boone County Research Landfill (KY), the average leachate composition of a New York City landfill, and the range of leachate characteristics of a Philadelphia landfill. Generally, the concentrations of $BOD_5$ and COD in the landfill leachates were 10 to more than 100 times higher than they were in the untreated sewage. Total phosphorus and total nitrogen concentrations were about five times higher in the leachates than in the sewage. Thus, the carbon-to-nitrogen ratio in the leachates appeared to be higher than in the raw sewage.

Mikucki, et al., also discussed the differences in concentrations of contaminants in leachate from landfills of different ages. Measurement of $BOD_5$ in the leachate of two landfills (20-years difference in age) showed that the leachate from the older landfill, which contained 18 mg/L $BOD_5$, was two orders of magnitude lower than from the newer landfill. The difference in ammonia concentrations in the leachates from the two sites was not as great; the leachate from the older site contained 100 mg/L and that from the newer site had 160 mg/L.

Mikucki et al., also reviewed potential problems of toxicity, metal precipitation, discoloration, oxygen depletion, and algal blooms associated with the discharge of landfill leachates to surface waters. This study also discussed potential health risks associated with compounds such as ethyl carbamate, p-cresol, o-xylene, and p-xylene in leachates.

Thomas[10] also reviewed the characteristics of leachate as reported in the literature. He indicated that Kurtz[11] presented results of bench-scale investigations on the treatability of landfill leachate mixed with influent from a municipal wastewater treatment plant (raw domestic wastewater) in a ratio of 2.2 parts influent to 1 part leachate. Thomas indicated that the bench-scale activated sludge treatment system removed up to 100 percent of the volatile organics in the leachate; the detention time for treatment was not specified.

This study is of interest because it is apparently the only one that presents concentrations of priority pollutants with reference to landfill leachate. However, as shown in Table 2, the data reported were the concentrations of priority pollutants not in the leachate itself, but rather in the leachate/wastewater mixture and in the effluent of the bench-scale treatment system. The concentrations of the priority pollutants measured in the treatment effluent were compared with November 1980 criteria;[12] these

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[9] W. J. Mikucki, E. D. Smith, R. Fileccia, J. Bandy, G. Gerdes, S. Kloster, G. Schanche, L. J. Benson, M. J. Staub, and M. A. Kamiya, *Characteristics, Control, and Treatment of Leachate at Military Installations*, Interim Report N-97/ADA097935 (U. S. Army Construction Engineering Research Laboratory [USA-CERL], 1981).

[10] A. W. Thomas, *The Characteristics and Treatment of Leachate From Sanitary Landfills*, Masters Project (Department of Civil and Environmental Engineering, New Jersey Institute of Technology, 1985).

[11] F. H. Kurtz, "Treatment of Leachate Wastes at a Central Treatment Plant," *New Jersey Effluents*, Vol 16, No. 14 (1982).

[12] USEPA, "Water Quality Criteria Documents, Availability," *Federal Register*, Vol 45, No. 231 (November 28, 1980).

## Table 2

**Priority Pollutants in Wastewater/Leachate Mixtures***
**(From F. H. Kurtz, "Treatment of Leachate Wastes at a Central Treatment Plant," *New Jersey Effluents*, Vol 16, No. 14 [1982]).**

**Removal of Priority Pollutant Heavy Metals at MCUA**

| Metal | Influent mg/L | Influent kg/d | Effluent mg/L | Effluent kg/d | % Removal |
|---|---|---|---|---|---|
| Antimony | 0.140 | 43.0 | 0.102 | 31.2 | 27.4 |
| Arsenic | 0.0181 | 5.3 | 0.0101 | 3.1 | 41.5 |
| Beryllium | 0.002 | 1.0 | 0.002 | 0.7 | 30.0 |
| Cadmium | 0.0342 | 10.2 | 0.0233 | 6.3 | 38.3 |
| Chromium | 0.106 | 31.3 | 0.054 | 15.9 | 49.2 |
| Copper | 1.35 | 400.7 | 0.40 | 119.8 | 70.2 |
| Lead | 0.78 | 230.1 | 0.21 | 63.8 | 72.3 |
| Mercury | 0.0027 | 0.8 | 0.0008 | 0.2 | 69.7 |
| Nickel | 0.12 | 36.2 | 0.09 | 28.0 | 22.8 |
| Selenium | 0.0071 | 2.2 | 0.0035 | 1.1 | 49.3 |
| Silver | 0.012 | 3.4 | 0.007 | 2.0 | 41.7 |
| Zinc | 8.2 | 2,436.0 | 4.4 | 1,315.0 | 46.0 |
| Cyanides | 0.48 | 137.3 | 0.06 | 16.5 | 88.0 |
| Total | | 3,337.5 | | 1,603.8 | 52.0 |

**Removal of Priority Pollutant Volatiles at MCUA**

| Volatiles | Influent mg/L | Influent kg/d | Effluent mg/L | Effluent kg/d | % Removal |
|---|---|---|---|---|---|
| Benzene | 0.224 | 70 | 0.001 | 0.3 | 99.6 |
| Carbon tetrachloride | 0.131 | 41 | 0.016 | 5 | 87.8 |
| Chlorobenzene | 0.005 | 1.55 | 0.001 | -- | 100.0 |
| 1,1-Dichloroethane | 0.002 | 0.62 | 0.001 | -- | 100.0 |
| 1,2-Dichloroethane | 6.582 | 2,043 | 4.420 | 1,372 | 32.9 |
| 1,1,1-Trichloroethane | 6.575 | 2,041 | 0.852 | 242 | 87.1 |
| 1,1,2,2-Tetrachloroethane | 0.0012 | 0.37 | 0.001 | -- | 100.0 |
| Chloroform | 0.118 | 37 | 0.059 | 18 | 51.4 |
| 1,1-Dichloroethylene | 0.031 | 9.62 | 0.002 | 0.62 | 93.6 |
| 1,2-Trans-dichloroethylene | 0.011 | 3.41 | 0.001 | 0.31 | 90.9 |
| 1,2-Dichloro propane | 0.438 | 135.96 | 0.002 | 0.62 | 99.5 |
| Ethyl benzene | 0.157 | 49 | 0.009 | 1.2 | 97.6 |
| Methylene chloride | 0.795 | 247 | 1.151 | 357 | 0.0 |
| Methyl chloride | 0.321 | 99.64 | 0.113 | 35.07 | 64.8 |
| Bromoform | 0.0008 | 0.25 | 0.0023 | 0.71 | 0.0 |
| Dichlorobromomethane | 0.010 | 3.10 | 0.0045 | 1.40 | 54.8 |
| Trichlorofluoromethane | 0.037 | 11.46 | 0.0008 | 0.25 | 97.8 |
| Chlorobromomethane | 0.0001 | 0.03 | 0.00016 | 0.05 | 0.0 |
| Tetrachloroethylene | 2.862 | 888 | 0.444 | 137 | 84.6 |
| Toluene | 4.845 | 1,504 | 0.009 | 2.8 | 99.8 |
| Trichloroethylene | 0.659 | 205 | 0.087 | 27.0 | 86.8 |
| Vinyl chloride | 0.015 | 4.66 | ND | -- | 100.0 |
| Total | | 7,395.67 | | 2,223.33*** | 69.9 |

*Based on six day sampling program in June, 1982
**ND - not detectable
***As reported by Kurtz. Actual total is 2,201.33

comparisons showed that of the heavy metals measured, concentrations of arsenic, cadmium, chromium, lead, mercury, and nickel in the effluent were a factor of four to more than three orders of magnitude higher than amounts deemed safe by human health criteria. The concentrations of several of the heavy metals were also high enough, and in some cases much higher than necessary, to cause chronic toxicity to aquatic life. While the concentrations of the volatile priority pollutants listed in Table 2 were below those generally of concern for toxicity to aquatic life, they were typically orders of magnitude above concentrations that result in a risk of one additional cancer per 1 million people over 70 years.[13]

The treatment program outlined by Thomas appears to have removed about 40 to 90 percent of the heavy metals and 90 percent or more of a variety of volatile priority pollutants; however, the concentrations remaining were high enough to likely require additional treatment before discharge to surface water or before being allowed to enter groundwaters. Furthermore, it is clear that only a small leak of leachate from a landfill site could potentially contaminate area groundwaters, if the contaminants moved through the substratum. Also, land run-off of leachate could contaminate surface waters with chemicals that are toxic to aquatic life and hazardous to human health. In surface waters, the bioconcentration in fish of persistent, low-water-solubility organics, such as polychlorinated biphenyls (PCBs) or chlorinated hydrocarbon pesticides, must also be considered. These materials can accumulate in fish tissue to the extent that it is unsuitable for human food.

Several priority pollutants represent potential hazards to humans and aquatic organisms at levels that cannot be measured by commonly used chemical analytical techniques.[14] This problem has caused some states to ban leachate recycle and illustrates the importance of the double-liner system and the unsaturated and saturated flow-monitoring program recommended for leachate recycle systems. The leachate collection system must be 100 percent effective, which would be very difficult if not impossible to attain and to maintain over a significant period of time, much less indefinitely.

### Exerience With Leachate Recycle

Table 3 summarizes the characteristics of the recycled leachates as reported by Pohland and Harper. Comparing these statistics with data presented for unrecycled leachate in Table 1 shows that the BOD, COD, and iron concentrations in leachate recycled through pilot-scale landfill systems for the durations listed were generally below the lower limit of the "typical" concentration ranges for unrecycled leachate. However, the concentrations of nearly all the parameters reported in Table 3 were within the overall ranges reported for unrecycled leachate (Table 1). The change in the amount of biodegradable organic matter remaining after leachate recycle was observed by Pohland and Harper in the reduction of the $BOD_5$-to-COD ratios in the leachate over time. The percentage of methane in the gas produced from the pilot-scale leachate recycle was at the upper end of the range presented for landfill leachates in Table 1.

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[13] USEPA.

[14] G. F. Lee and R. A. Jones, "Water Quality Monitoring at Hazardous Waste Disposal Sites: Is Public Health Protection Possible Through Monitoring Programs?", *Proceedings of Third National Water Well Association Symposium, Aquifer Restoration and Groundwater Monitoring*, Worthington, OH (1983).

## Table 3

**Leachate Chartacteristics and Gas Production From Pilot-Scale Recycle Facilities**
(From F. G. Pohland and S. R. Harper, "Critical Review and Summary of Leachate and Gas Production from Landfills," Draft Report (Hazardous Waste Environmental Research Laboratory, USEPA, 1985).

| | | | | Leachate composition at end of recycle* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Test variables | Test time (days) | Frequency of recycling | $BOD_5$ | COD | $BOD_5$/COD | TKN | pH | Fe | Zn | % Methane |
| Sonoma County Solid Waste Stabilizaion Study by EMCON Assoc. of CA | Recycling only | 1440 | Daily | 400 | 1500 | 0.3 | 200. | 6.5 | 50 | 1.0 | 65 |
| Georgia Tech's pilot-scale investigation, Atlanta, GA | Recycle and pH control | 747 | — | 35 | 240 | 0.15 | 8.5 | 7.0 | 3 | 0.2 | 65 |
| | Recycle, pH control, and microbial seeding | 747 | — | 40 | 170 | 0.2 | 1.4 | 7.0 | 9 | 0.4 | 65 |
| Univ. of Louisville pilot-scale study, Louisville, KY | Recycle and pH control | 514 | Daily | 200 | 350 | 0.6 | 36. | 7.0 | 7 | 0.2 | — |
| | Recycle, pH control, and nutrient addition | 514 | Daily | 200 | 350 | 0.6 | 330. | 7.0 | 6 | 0.7 | — |
| **, reported in Proceedings of GRCDA Sixth International Landfill Gas Symp. Industry Hills, CA by Walsh*** | Control, no recycle, and no water addition | 720 | Daily | — | 36,000 | — | 825. | 6.3 | — | — | 65 |
| | Control with recycle | 720 | Daily | — | 26,000 | — | 875. | 6.8 | — | — | 70 |

*All units in mg/L except $BOD_5$/COD and pH.
**Indicates information not provided by author.
***J. J. Walsh, W. G. Vogt, and W. M. Held, "Demonstration of Landfill Gas Enhancement Techniques in Landfill Simulators," In: Proceedings of GRCDA Sixth International Landfill Gas Symposium, Industry Hills, CA (1983).

At present, the literature does not show the results of any full-scale leachate recycle studies conducted in the United States. The Mountain View project of California is a demonstration project that was designed to verify the results of pilot-scale investigations in leachate recycle. According to Pohland and Harper, the demonstration landfill site had six cells, each containing $5.3 \times 10^6$ tons ($4.8 \times 10^6$ tonnes) of garbage with an average volume of 10 500 $m^3$ each. The cells, with or without leachate recycle, were treated differently with regard to moisture control, pH adjustment, sludge seeding, and nutrient addition. Although the recycling was somewhat erratic, leachate recycling with moisture and pH control provided higher gas yields than the control cells. Routine leachate analysis was not performed in this study. Therefore, it is difficult to present any definitive conclusion on improvement in leachate quality that may result from recycling.

Robinson, et al.,[15] discussed leachate recirculation at a heavy-polyethylene-lined landfill (2.5 ha) in England. Here, the rate of COD reduction in the recycled leachate was higher than that at sites without recirculation. No data were available on gas production because the landfill was not covered. Barber[16] surveyed several water authorities in the United Kingdom that are using leachate recycling to treat landfill leachate. Several landfills use land irrigation, sewer disposal and treatment, and on-site treatment as alternate means for leachate treatment. Table 4 presents the percent of the total number of sites at which leachate recirculation is being practiced that provide some type of treatment.

According to Barber, recycling can convert leachate to "low strength" (undefined by him) in about 18 months. He also indicated that additional, follow-on treatment, such as combining the leachate with sewage biological treatment, would improve the final leachate quality and make it "suitable" for discharge to surface waters, although he did not provide complete chemical characterization for judging the discharge's "suitability."

Cord-Landwher, et al.,[17] reported the use of leachate recycle on a full-scale basis at several landfill sites in Germany. At one site, leachate was collected from a new section of the landfill and recycled at an older, stabilized section. Pohland and Harper indicated that this approach can help obtain consistent quantities of gas from the landfill. Also, collecting leachate from a new section that is not equipped with gas collection and leachate recirculation systems, and stabilizing it at an older site that already has this equipment will minimize capital investment for leachate recycle with gas collection.

Pohland and Harper have presented data (obtained from Cord-Landwher) on the concentrations of $BOD_5$ and COD at the stabilized and unstabilized sections of the above-mentioned site on one day. The data showed that the leachate from the older site contained 99 percent less $BOD_5$ and 90 percent less COD than the leachate from the new

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[15] H. D. Robinson, C. Barber, and P. J. Maris, "Generation and Treatment of Leachate from Domestic Waste in Landfills," *Journ. Water Pollut. Control Fed.*, Vol 54 (1982), p 465.

[16] C. Barber, *Treatment and Disposal of Leachate from Domestic Solid Wastes in Landfills: Current Practice and Research at Hydrogeologically Secure Landfill Sites*, Report to Water Research Center, Stevenage, U.K. (1983).

[17] K. Cord-Landwher, H. Doedens, H. Elsen, and H. Kospel, "Stabilization of Landfills by Leachate Recycle," In: *Proceedings of BMFT Status Seminar*, Berlin, Germany (November 1982).

**Table 4**

**Summary of UK Landfills Using Leachate Recycling as a Method of Landfill Leachate Treatment**
(Based on information from C. Barber, *Treatment and Disposal of Leachate from Domestic Solid Wastes in Landfills: Current Practice and Research at Hydrogeologically Secure Landfill Sites*, Report to Water Research Center, Stevenage, U.K. [1983].)

| Water authority | % of sites using leachate recycle | Total number of sites where treatment was carried out |
|---|---|---|
| Anglian | 55 | 12 |
| Southern | 45 | 14 |
| Severn-Trent | 45 | 34 |
| Wessex | 20 | 11 |

site. However, they did not indicate the period of recycle needed at the new site to achieve these $BOD_5$ and COD reductions, so this amount of removal cannot properly be compared to that reported in other studies. Thus, it is not possible to determine whether recycling new leachate at an already stabilized section offers any advantages or disadvantages in terms of how quickly the biodegradable organic matter stabilizes. The implications of this process in terms of stabilizing a new landfill are also unclear. Since recycling is not occurring at the new site, it would seem that advantages such as uniform moisture would not be available, and there would not be a greater rate of stabilization. This method would appear to have advantages in the areas of cost, leachate disposal, and gas production, but not necessarily provide an increased stabilization rate at the new site or the ability to use the older, stabilized site for other purposes.

Cord-Landwher also compiled information on leachate characteristics at nine full-scale leachate recycle facilities in Germany. The sizes of the sites ranged from 2.5 ha to 18 ha, and precipitation ranged from 650 to 1100 mm. The annual volumes of leachate produced ranged from 570 to 7630 $m^3$. Pohland and Harper reported that concentrations found in the leachates (following 3 to 10 years of recycle) were 100 to 20000 mg/L of BODs and 900 to 48000 mg/L of COD. At one site, the $BOD_5$-to-COD ratio was 0.003, indicating a low proportion of biodegradable organic matter compared to total COD. However, to draw conclusions regarding the leachate's "stability" such a ratio should be reviewed in light of the initial values and current actual concentrations of BOD and COD. Compared to the ranges of concentrations found in unrecycled landfill leachate (Table 1), these concentration values fell within the ranges reported.

Several studies[18] of pilot-scale sites reported accelerated stabilization of biodegradable organic domestic and industrial wastes in municipal landfills. Leckie, et al.,[19] also reported a large reduction in $BOD_5$ and COD at a Sonoma County, CA, landfill using leachate recirculation. Tittlebaum[20] reported on the stabilization of heavy metals and organic carbon in a pilot-scale landfill at the University of Louisville that used leachate recirculation. Thus, the literature strongly indicates that leachate recycle will decrease the time needed to decompose biodegradable organic matter within a municipal landfill. What it will accomplish in terms of heavy metal and priority pollutant reductions has not been well documented.

**Removal of Heavy Metals**

Pohland, et al.,[21] noted that leachate containment and recycling not only accelerates the stabilization process, but also establishes and protects the biologically mediated reducing conditions suitable for forming sulfide, which may precipitate with heavy metals. It also provides the physical system to filter out the precipitated heavy metals.

Pohland and Harper observed that removal of heavy metals, including cadmium, chromium, copper, lead, nickel, iron, and zinc, occured in pilot-scale leachate recycle systems. This removal was attributed to complexation reactions. Knox and Jones[22] studied the tendency of sanitary landfill leachate to complex with cadmium in four sanitary landfill leachates in southern Ontario. In on case, they concluded that complexation was due mainly to low-molecular-weight organic compounds and that their behavior was consistent with that of carboxylic acids. In another case, it was attributed to high-molecular-weight (mw > 10,000) compounds, and their behavior suggested that they might contain phenolic hydroxyl groups. No definitive conclusion was made other

[18] F. G. Pohland, "Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment," EPA-600/2-75-043 (USEPA, 1975); F. G. Pohland, "Landfill Management With Leachate Recycle and Treatment: An Overview," In: *Proceedings of a Research Symposium, Gas and Leachate From Landfills: Formation, Collection, and Treatment*, EPA-600/9-76-004 (USEPA, 1976) pp 159-167; F. G. Pohland, "Leachate Recycle as Landfill Management Option," *Journ. Env. Engr. Div. ASCE*, Vol 106(EE6) (1980), pp 1057-1069; F. G. Pohland and J. P. Gould, "Stabilization at Municipal Landfills Containing Industrial Wastes," In: *Proceedings of Sixth Annual Research Symposium, Disposal of Hazardous Waste*, EPA-600/9-80-010 (USEPA, 1980), pp 242-253; F. G. Pohland, D. E. Shank, R. E. Benson, and H. H. Timmerman, "Pilot-Scale Investigation of Accelerated Landfill Stabilization With Leachate Recycle," In: *Proceedings of Fifth Annual Research Symposium, Municipal Solid Waste: Land Disposal*, EPA-600/9-79-023a (USEPA, 1979), pp 283-295.

[19] J. O. Leckie, J. G. Pacey, and C. Halvadakis, "Landfill Management with Moisture Control," *Journ. Env. Engr. Div. ASCE*, Vol 105(EE2) (1979), pp 337-355.

[20] M. E. Tittlebaum, *Investigation of Leachate Heavy Metal and Organic Carbon Content Stabilization Through Leachate Recirculation*, Doctoral Dissertation, Interdisciplinary Studies (University of Louisville, 1979).

[21] F. G. Pohland, J. P. Gould, R. E. Ramsey, B. J. Spiller, and W. R. Esteves, "Containment of Heavy Metals in Landfills with Leachate Recycle," In: *Proceedings of Seventh Annual Research Symposium, Municipal Solid Waste: Land Disposal*, EPA-600/9-81-002a (USEPA, 1981).

[22] K. Knox and P. H. Jones, "Complexation Characteristics of Sanitary Landfill Leachates," *Water Research*, Vol 13 (1979), p 839.

than to indicate that several factors influence complexation of heavy metals; these include the relative concentrations of other constituents, pH, and redox conditions.

It appears that in laboratory systems, some heavy metal removal occurs during leachate recycle and, at least for zinc, the removal is enhanced by maintaining a neutral rather than a lower pH, since the higher pH is more conducive to precipitation reactions. Pohland and Gould suggested that because of the reductions observed in heavy metal concentrations in leachate during recycle, at least in laboratory lysimeter systems, consideration should be given to co-disposal of municipal and certain industrial wastes in landfills that practice leachate recycle. They supported this position by indicating that there are few documented cases of groundwater contamination by heavy metals near municipal landfills that use co-disposal.

The migration of heavy metals from a landfill is of concern if leachate recycle is used to remove them from the leachate. Migration characteristics would depend on the forms of the metals and their concentrations, the pH and redox conditions in the landfill and environs, the presence of other materials in the landfill such as complexing organics, sulfides, carbonates for precipitation, and the presence of materials that would adsorb heavy metals, such as clay minerals and iron. Precipitated metals may be removed and prevented from migrating by the physical straining in the solid mass during recycling. The conditions would have to be evaluated on a site-specific basis.

Pohland and Gould suggested that regulations (unspecified) governing the disposal of materials containing elevated concentrations of heavy metals in municipal landfills are ultra-restrictive and might not be justifiable if the leachate is recycled, based on the behavior of potential contaminants in a landfill leachate being recycled. However, it should be noted that once the degradable organics become stabilized, the heavy metals which had precipitated as sulfides could dissolve. If the system becomes oxic, these metals could potentially re-precipitate in other forms such as carbonates or hydroxides; in other cases, they may become mobilized. However, it is doubtful that a stabilized landfill would become a significant source of heavy metal contamination of leachate; once the system becomes oxic, the large amounts of iron typically in leachate will precipitate as an iron hydroxide, which is a highly efficient scavenger for other heavy metals.

**Enhancement of Leachate Recycle Effectiveness**

In an attempt to optimize the recycle treatment system further, a number of investigators have studied the impacts of manipulating the pH of the leachate before recycle, the nutrient concentrations of the leachate, and the microbial populations in the system. The following sections summarize these studies.

*pH Control of Leachate*

Pohland and Harper reported on the characteristics of the pH of leachate over the recycle period. The pH initially decreases as the microorganisms become acclimated and begin to generate volatile organic acids. As these acids are converted to methane and other more refractory materials and as the bicarbonate buffering system is established, there is a general increase in pH.

A number of studies have investigated the impact of pH and controlling pH on the effectiveness of leachate recycle for solid wastes. In laboratory lysimeter studies, using about 1-m-diameter systems packed with about 3 m of compacted refuse (mostly paper, garbage, garden debris, and glass), Pohland[23] investigated the impact on leachate characteristics of adjusting the leachate's pH to nearly neutral before recycling it through the lysimeter system. This provided conditions more conducive to the growth of methane-forming bacteria. About 30 gal (113 L) of primary sewage sludge were added in three layers to the refuse in the lysimeter of a second test system. It was thought that by adding microorganisms to the "landfill" system, the stabilization rate would be increased, since the acclimatization and initial lag period might be shortened. Pohland observed that adding sewage sludge to the system increased the amount of sodium hydroxide needed to maintain a neutral pH, indicating that the system was producing greater amounts of acid. A third system used only leachate recycle, and a fourth (the "control") received only simulated rainfall. Figure 1 shows representative results of these experiments. As shown, addition of the microorganisms appeared only to add to the acid production; rather than decreasing the time needed for stabilization, it actually increased it by about 6 months beyond that required by the system in which only pH was adjusted. The patterns for $BOD_5$ concentration in the leachate over time were similar to those for total volatile acid concentration over time shown in Figure 1.

The overall results of this study (Figure 1) show that the three systems involving leachate recycle had the same pattern of volatile acid concentration in the leachate over time. They also showed similar rates of decrease following the initial rise in volatile acid concentration in the leachate. The major differences were in the concentrations of volatile acid in the leachate and the total time for essential cessation of volatile acid production. The recycle system in which the leachate pH was adjusted to neutral before recycle was the first system to stop producing volatile acid and had the lowest concentrations of volatile acids. The leachate recycle system with sludge addition and pH control took longer to stop producing volatile acids than the leachate recycle system without pH adjustment; it also had higher volatile acid concentrations. This was likely related to the additional formation of volatile acids from the sewage sludge. The rapid decline in volatile acid content in the simple recycle system corresponded, as expected, to an increase in the leachate's pH. The control system shown in Figure 1 did not have leachate recycle and received only the equivalent of rainfall water input. Comparison of the pattern of volatile acid concentration in the leachate from this system with that in the leachate from the recycle systems shows that recycling shortened the time needed to stop acid production. It appears that the control system microorganisms took longer to begin acid production, and that without leachate recycle, acid production continued at several thousand mg/L during the entire 3-year study period.

The lysimeter "landfill" system that received sewage sludge and pH control produced gas earlier than the leachate recycle system with pH control only. While Pohland reportedly found it hard to measure the volumes of gas produced, he did report that the methane content of the gas produced was greater than 60 percent for both systems.

Tittlebaum studied leachate recycling in laboratory lysimeter systems about 1m in diameter, with about 2.5 m of compacted shredded or unshredded refuse. In the control, tap water was added to simulate rainfall; however, the pH of the leachate generated was not reported. In one test system, he maintained leachate pH at about 7 by adding sodium hydroxide, and recycled the leachate to maintain about 70 percent moisture content in the system. In another system, he varied the pH between 4 and 8 to determine the impact of leachate pH on heavy metal removal during recycling. However, since he

[23] F. G. Pohland, *Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment.*

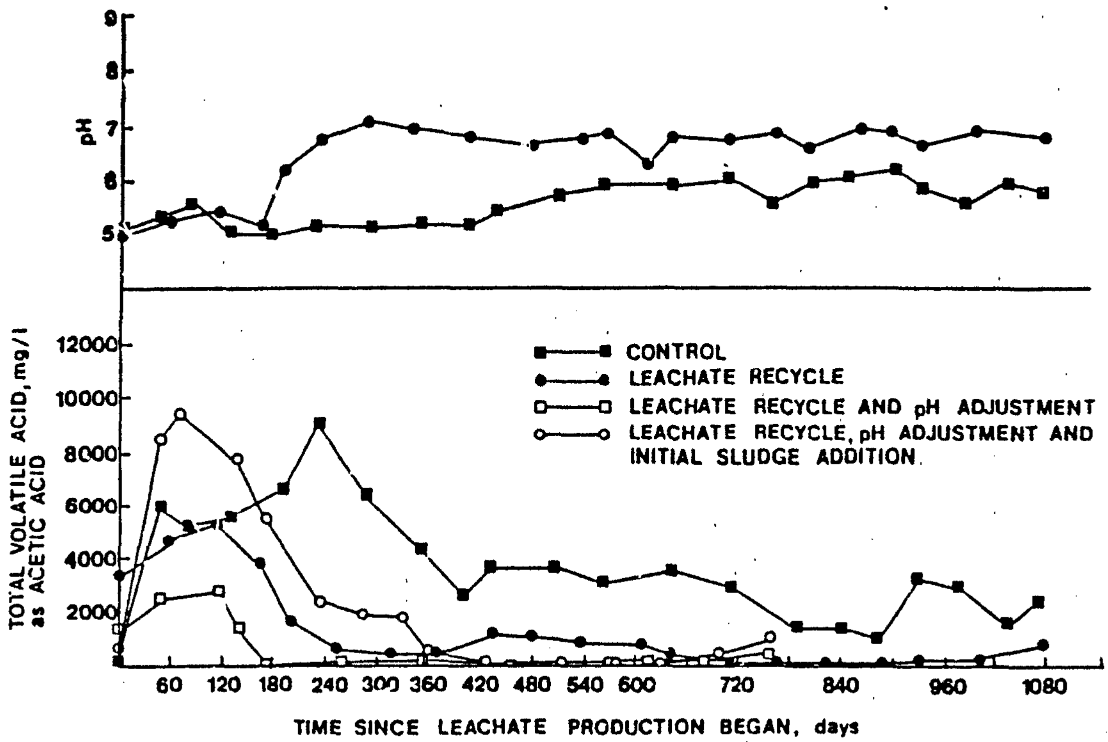


**Figure 1. pH and total volatile acid concentrations in leachate under test conditions.** (From F. G. Pohland, *Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment*, EPA-600/2-75-043 [USEPA, 1975].)

ated was not reported. In one test system, he maintained leachate pH at about 7 by adding sodium hydroxide, and recycled the leachate to maintain about 70 percent moisture content in the system. In another system, he varied the pH between 4 and 8 to determine the impact of leachate pH on heavy metal removal during recycling. However, since he apparently did not maintain a constant pH in the leachate, but rather varied it somewhat randomly, these results are not readily interpretable.

Tittlebaum's results were similar to those of Pohland.[24] In general, leachate pH increased up to day 317 and gradually decreased to about 7 by the end of the experiment (day 514). By the end of the experiment, concentrations of total volatile acids, COD, $BOD_5$, and TOC in the control were more than 10 times the concentrations found in the other test chambers. In fact, the control cell showed no decrease in concentration for any of these parameters during the entire experiment. Tittlebaum's measurements of selected heavy metals, copper, chromium, iron, lead, mercury, and zinc showed removal of heavy metals with recycle; however, in comparison to the controlled neutral-pH system, varying the pH had no impact on metal removal. He found that varying the pH between 4 and 8 produced higher concentrations of zinc than in the pH neutral system. In the control system, which received only simulated rain and no recycle, the effluent zinc concentration was as high as 0.97 mg/L. The zinc concentration in leachate from the system whose pH was varied between 4 and 8 was as high as 5 mg/L.

[24]F. G. Pohland, *Sanitary Landfill Stabilization With Leachate Recycle and Residual Treatment.*

while maintaining a neutral pH did not increase the stabilization rate of volatile acid or organic concentrations in the leachate.

*Nutrient Requirements for Leachate Recycle*

Microorganisms generally use major nutrients in the atomic proportions of about 106 C, 16 N, and 1 P. Therefore, it might be expected that with the high BOD content of municipal landfills, the growth of the microorganisms responsible for decomposing the organics could be limited by the amounts of available nutrients in the system. For optimum organic matter decomposition with leachate recycle, some nutrient augmentation might be desirable. The impact of adding nutrients to leachate recycle has not been investigated widely.

Tittlebaum evaluated the impact on volatile organic acids and organics stabilization by supplementing the leachate (with pH controlled to neutral) being recycled with ammonium nitrate through addition of shredded or nonshredded garbage. Maintaining a 100:20:1 atomic ratio of C:N:P with nutrient augmentation, as compared with the unspecified ratio found for leachates without nitrogen augmentation, did not improve the extent of stabilization.

*Gas Production During Leachate Recycle*

Gas produced by landfills is a potentially important resource. Therefore, it is of interest to investigate the quantities of gas produced in leachate recycle systems and the percentage of methane in the gas. Pohland[25] measured the percent carbon dioxide and methane content of the gas produced in his lysimeter systems (described on pp 18-21), but he did not measure the volumes of gas produced. In the system augmented with sewage sludge and in which the leachate pH was controlled to neutral, the gas produced was as much as 82 percent methane. While gas production appeared somewhat more rapidly in this system with addition of the methane-forming bacteria, methanogen performance was apparently inhibited during the early part of the recycle experiment; this was believed to result from the excessive amounts of acid formed. After neutralizatrion of the excess acid, the rate of methane formation was similar to that of the other recycle systems. The systems operated with only leachate pH control produced gas containing about 76 percent methane. These percentages are higher than the 60 to 65 percent normally reported for anaerobic sludge digestion. In terms of gas production, the overall advantage of the sludge augmentation is not that there is significant difference in the composition of the gas, but rather that gas is produced earlier.

Pohland, et al.,[26] reported substantial amounts of gas production at the pilot-scale leachate recycle system. One cell was covered to measure and characterize gas production. After 300 days of recycling, gas production began increasing and stabilized at the increased rate 3 to 4 months later. Methane composition varied from 40 to 50 percent. In this system, there had been no pH control or sludge seeding, only recycle.

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[25]F. G. Pohland, *Sanitary Landfill Stubilization With Leachate Recycle and Residaul Treatment.*

[26]F. G. Pohland, D. E. Shank, R. E. Benson, and H. H. Timmerman.

## Literature Summary

It appears that leachate recycle offers a mechanism for increasing the rate at which biodegradable organic matter within a landfill becomes stabilized with respect to methane formation. The process of leachate recirculation appears to improve the homogeneity of the waste's moisture content and thus provides a better environment for microbial activity. More rapid "stabilization" will likely allow the land to be re-used sooner. Recycle would be expected to provide partial disposal of the leachate by means of evapotranspiration at the landfill's surface. It also appears that recycle may improve the methane composition of gas produced in the landfill.

However, other considerations about recycle pose questions about its general utility. For example, the additional hydraulic loading on the landfill system may enhance the possibility of groundwater contamination from the leachate constituents and will be a controlling factor on how much leachate can be recycled at a given site. Besides the biodegradable organic matter, numerous other leachate components must be considered in evaluating the effectiveness of recycle as a leachate "treatment." For example, there is evidence to suggest that recycle may enhance the removal of some heavy metals and certain volatile organics. However, there is minimal documentation for this, and the long-term implications have yet to be addressed. Furthermore, while studies have indicated considerable percentage reductions in some of these compounds, the concentrations remaining after treatment are high enough to be of environmental and/or human health concern. Thus, even with recycle, additional leachate treatment will be required before discharge to surface or groundwaters.

# 3 PROBLEMS WITH LEACHATE RECYCLE

Several problems will be encountered in developing and implementing leachate recycle systems. These would be especially evident if existing landfills were converted to recycle, because they have the least controlled hydraulic characteristics, and may not be amenable to total leachate collection. This chapter discusses some of the major concerns.

Some sites will require disposal of leachate recycle "blowdown"—the leachate that has been treated to the degree that it will be in the system and that is then bled off. There must also be a way to dispose of excess leachate that cannot be treated at a recycle facility due to its hydraulic capacity. While a particular system's hydraulic capacity will determine, to some extent, how much leachate will be "excess," it is expected that at all sites there will be some "excess" associated with precipitation from major storms. It is evident that recirculation can reduce the concentration of BOD and volatile organic acids in leachate; however, Barber concluded that the concentration of ammonia in the leachate after recycle will likely still remain high—as high as several hundred mg N/L. This, and the presence of heavy metals and other potentially toxic components of recycled leachate, will require some post-recycle treatment [illegible] as provisions for disposing of the effluent.

The hydrology of a candidate landfill site must be properly considered. This will be especially important in converting existing sites to recycling. It is important to understand and quantify the site's water balance to design for the amount of leachate that can be handled, the amounts and types of additional leachate treatment that will be needed, and the fate and transport or certain contaminants in the leachate. Landfills typically use low-permeability soils or clay for surface cover. However, because of the characteristically lower infiltration rate of these materials, recirculation of leachate by surface spraying or ponding could produce a hard-pan, which could further reduce the infiltration rate. This would minimize the effectiveness of surface spraying leachate to effect recycle. Furthermore, using intermediate covers of clay-type soils within the waste for daily cover could produce perched areas of saturation and uneven moisture content that could leave areas of waste unsaturated. Under these conditions, or if the landfill were lined with low-permeability material, leachate that exceeded the landfill's recycling capacity could surface or move laterally.[27] Surface plowing or furrowing may help the surface soil restore its initial or near-initial infiltration capacity. Leachate to be recycled should be introduced within the landfill so that it is more likely to be evenly distributed.

In most cases, recirculation of leachate alone will not produce leachate that is suitable for surface water discharge. Aerobic treatment, combined treatment with domestic sewage, and/or other treatment may be needed to achieve effluent characteristics suitable for surface water discharge. Chapter 4 analyzes the economics of the treatment trains for recycled leachate.

Some states have laws that affect leachate recycling. To determine the current legal status of leachate recycling at landfill sites, letters were written to the environmental protection departments (or equivalent agencies) of all 50 states; however, only sixteen replies were received. Massachusetts and Maine allow leachate recycling at landfill sites, but New Jersey, Maryland, and Virginia do not, because their annual

[27] C. Barber.

precipitation exceeds total annual evapotranspiration; under such conditions, the recycled leachate would increase the moisture in the solid waste columns and produce more leachate.

Several states, including New Jersey, have criteria for municipal landfills which specify that the hydraulic head of the leachate on the bottom liner should never exceed 1 ft (0.3048 m).[28] Most of the currently operated landfills are not designed to handle the additional head created by leachate recycle. A survey of leachate treatment approaches at 14 landfills in New Jersey found that certain landfills should not be allowed to operate. For example, one facility has been closed by court order at the request of the New Jersey Department of Environmental Protection. One of the landfills surveyed sends its leachate in tank trucks to large sewage treatment plants for further treatment. Others follow similar practices.

Leachate recycling at landfills, especially in humid areas, will require many restrictions and management regulations, because the current landfills are not designed to handle leachate problems properly.

[28]G. F. Lee, Personal communication with New Jersey Department of Environmental Protection (1985).

## 4 DESIGN CONSIDERATIONS

Maintaining the effectiveness of leachate recycle as a leachate treatment requires landfills that are properly operated and properly designed to handle the additional water load. The area's unsaturated and saturated groundwaters must be monitored for leachate migration. Such sites must also be associated with a facility that provides final treatment for excess leachate and blowdown. This chapter discusses some of the design considerations for establishing a leachate recycle system that provides partial leachate treatment.

### Site Selection

The landfill should not be affected by high groundwater or unstable soil slopes. The uplift pressure on the bottom of the liner should be released by properly designed and installed pressure release wells to minimize crack formation in the bottom clay layer. Similarly, the top of the landfill must be closed before the side slopes become excessive. The stability of the slopes of a garbage mass differs from that of a soil mass and is often difficult to predict.

### Lining

The concept behind lining an on-land waste disposal area is containing the wastes and the generated leachate in a clay or plastic "boat."[29] However, interactions with components within the landfill cells or problems in the placement of the liner will eventually cause any type of liner to leak. Many municipal landfills that are now in use are not lined, or the lining is not intact. Many states and Federal regulating agencies require that the liner material have a maximum permeability of $10^{-7}$ cm/s and that the hydraulic head on the liner not exceed 1 ft (0.3048 m). However, tests for this degree of permeability are typically done with tap water, whose makeup differs greatly from that of materials generated in the landfill. Investigations of the effects of synthetic organic solvents on compacted clay layers have shown that a liner's permeability to these types of materials can be much different than it is for water.[30] Before being used in the field, the liner material should also be subjected to tests such as shrink-swell and permeability to a single or complex mixture resembling leachate.

In response to RCRA's double-liner and leachate collection requirements, the USEPA has recently provided its own criteria for municipal landfill liners.[31] There are two major double-liner designs (Figure 2). One is a single synthetic liner on top of a thick, recompacted clay liner. The other incorporates two synthetic liners: the bottom liner is placed on a clay liner 24 in. (600 mm) or more thick. As shown in Figure 2, underdrains with laterals collect and remove the leachate from the landfills. These drains are placed in granular media that offer little resistance to flow and have high hydraulic conductivity.

A slight modification of the first U.S. Environmental Protection Agency (USEPA) double-liner design is suggested for use at a municipal landfill using recycle (Figure 3).

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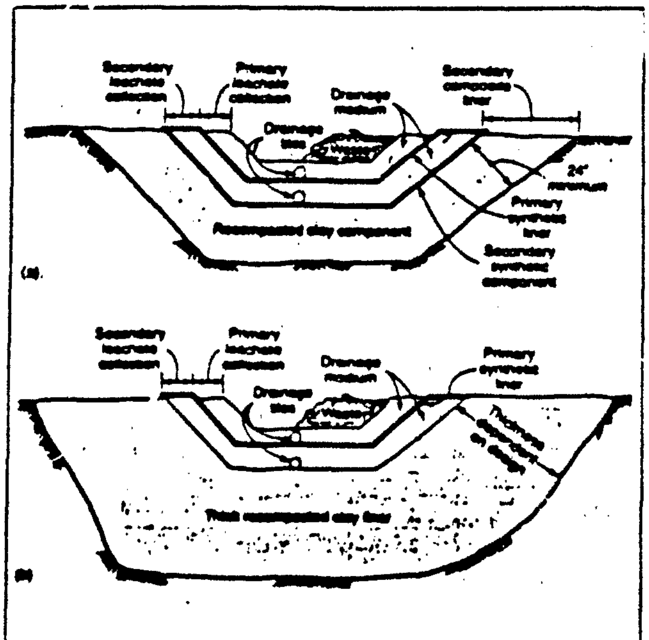
[29] W. J. Green, G. F. Lee, and R. A. Jones, "Clay Soil Permeability and Hazardous Waste Storage," *Journ. Water Pollut. Control Fed.*, Vol 53 (1981), pp 1347-1354.

[30] W. J. Green, G. F. Lee, and R. A. Jones.

[31] C. S. Bernstein, "Hammering Out a New RCRA," *Civil Engineering* (April 1985), pp 57-60.




The synthetic/composite double landfill liner system (a) consists of a membrane liner on top and a bottom liner made of a second membrane liner atop a clay liner. The other alternative has a membrane liner on top, and its secondary liner is compacted clay (b). The two designs incorporate leachate protection. (Courtesy of EPA)

**Figure 2. Principle designs for sanitary landfills.** (From C. S. Bernstein, "Hammering Out a New RCRA," *Civil Engineering* [April 1985], pp 57-60.)

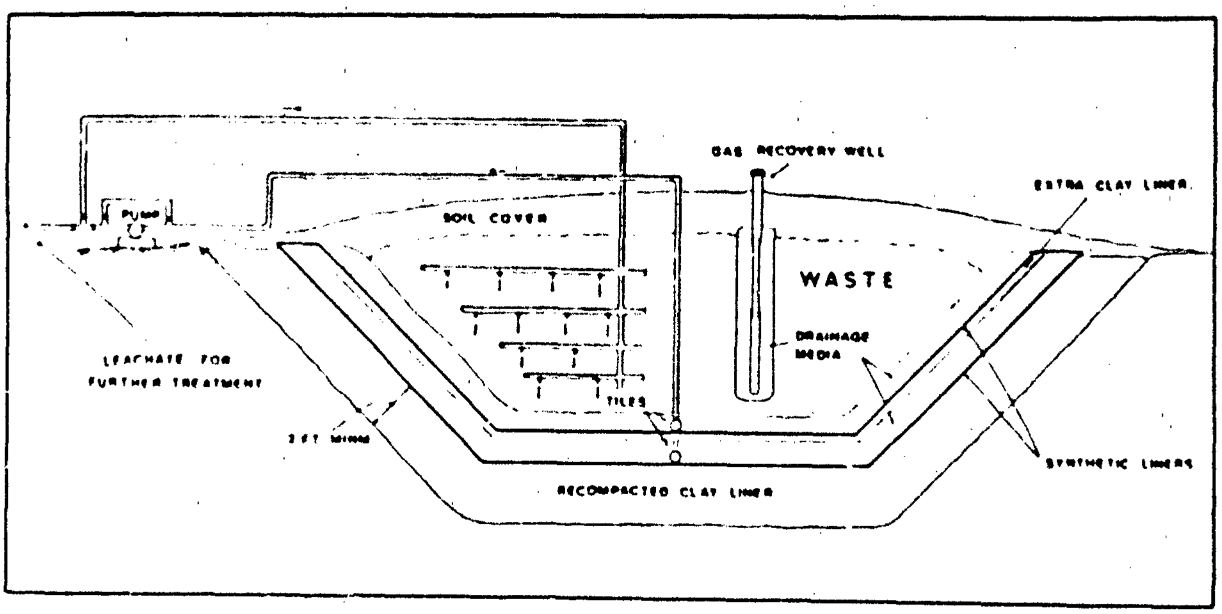



**Figure 3. Suggested design for landfill leachate recycle system with gas reclamation.**

A clay liner would be placed below the bottom-most synthetic liner, and the lower drainage medium would be placed beneath the entire system. This system would provide extra protection in the likely event that the upper synthetic liner is punctured by heavy machinery during installation, or eventually deteriorates due to contact with the leachate. The upper synthetic liner should be placed on top of the lower synthetic liner with a leachate collection system in between. A leachate collection system of porous material and of the appropriate slope should be placed to collect leachate not retained by the upper liner. The presence of leachate at this level is a warning that the upper synthetic liner has failed.

A landfill with leachate recycling should have sloping lateral drains at various levels in the refuse to bring the seeping leachate to a bottom drain. A hydraulic sensor switch would activate a pump if or when the liquid level exceeded a predetermined head. (This should never be more than 1 ft [0.3048 m].) The leachate to be recycled should be injected at various levels through vertical pipes. It may be necessary to spray the leachate over the top of the landfill; however, this option is less desirable, since perched areas of saturation could form, and produce a less homogeneous moisture content within the system.

### Gas Collection

It may be desirable to collect the gas produced from a leachate recycle system. Figure 3 shows the details of the top seal required for installation of a gas recovery system.

### Post-Recycle Treatment

After the recycling has treated the leachate as much as it can, the blowdown and the excess leachate must undergo additional treatment before being discharged. This can be done by an aerated lagoon or by activated sludge treatment. It is becoming increasingly evident that certain priority pollutants are best treated anaerobically. Therefore, an anaerobic lagoon or anaerobic filter should be investigated as a means of degrading some of the more persistent priority pollutants occurring in the leachate. Consideration must be given not only to degradation of parent compounds, but also to degradation of toxic transformation products produced during the treatment. Another potentially useful treatment scheme for removing priority pollutants is the combination of activated sludge treatment with activated carbon treatment. It is likely that in the next few years, research on hazardous waste treatment technology will provide a great deal of new information for improving treatment of complex mixtures of high-strength wastes.

### Costs

If a landfill is properly designed, lined, and monitored, recycling can be cost-effective. Chain and DeWalle[12] have provided a cost analysis for choosing treatments for final polishing that will further reduce concentrations of biodegradable organics in leachate. For low-strength leachates ($BOD_5 \leq 5000$ mg/L) at high flow rates (about

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[12] E. S. Chain and F. B. DeWalle, *Evaluation of Leachate Treatment, Volume I: Characterization of Leachate.*

75 L/min), the aerated lagoons were the least expensive. Anaerobic filters (attached-growth, anaerobic treatment system) work well at high $BOD_5$ concentrations (up to 20000 mg/L). In considering overall costs, the benefit of gas production should be considered. Table 5 compares the cost of leachate treatment at various $BOD_5$ concentrations and flow rates for achieving a specified reduction in biodegradable organics. Table 5 provides the influent concentrations in terms of $BOD_5$ and the effluent concentrations in terms of COD. The ratios of $BOD_5$/COD in the influent and effluent are not known. From the table, it appears that combined treatment with activated sludge or treatment with an aerated lagoon, followed by sand filtration and activated carbon are among the most cost-effective treatment methods.

If leachate recycle is implemented at a large landfill, the flow rate remains relatively high. There is a substantial reduction in effluent $BOD_5$ from the recycled landfill site. Here, the cost of leachate treatment--either with the activated sludge system or combined with an aerated lagoon, sand filtration, and activated carbon--will be much lower than the respective cost of \$6 or \$7.30 per 1000 gal (3785 L) of leachate (in 1975 dollars).

This analysis does not consider the cost of transporting the leachate to the activated sludge units. If the treatment plant were far from the landfill, then the cost of transportation should be added.

## Table 5

**Summary of Cost Estimates for Leachate Treatment**
(Derived from E. S. Chain and F. B. DeWalle,
*Evaluation of Leachate Treatment, Volume II: Characterization of Leachate*, EPA-600/2-77-186b
[U.S. Environmental Protection Agency, 1977b]).

| | Leachate (gal/min)* | Typical effluent COD (mg/L) | | Cost of treatment ($/1000 gal leachate) | |
|---|---|---|---|---|---|
| Influent BOD (mg/L) | | 25,000 | 5,000 | 25,000 | 5,000 |
| Activated sludge (AS) | 20 | 30 | 30 | 23.6 | 6.0 |
| (Combined treatment) | 2 | 30 | 30 | 41.4 | 11.9 |
| Aerated lagoon (AL) | 20 | 500 | 100 | 17.9 | 4.1 |
| | 2 | 500 | 100 | 31.6 | 10.0 |
| Anaerobic filter (AF) | 20 | 1500 | 300 | 22.1 (17.9)** | 6.8 (5.9) |
| | 2 | 1500 | 300 | 43. (38.8) | 17.7 (16.8) |
| AL-Sand filter (SF) | 20 | 125 | 25 | 25.7 | 7.3 |
| -Activated carbon (AC) | 2 | 125 | 25 | 39.9 | 13.7 |
| AL-SF-AC-Reverse | 20 | 25 | 5 | 27.6 | 9.2 |
| osmosis (RO) | 2 | 25 | 5 | 44.6 | 18.4 |
| AF-SF-AC | 20 | 375 | 75 | 32.8 (28.6) | 10.6 (9.7) |
| | 2 | 375 | 75 | 54.2 (50) | 22.0 (21.1) |
| AF-SF-AC-RO*** | 20 | 75 | 15 | 34.7 (30.4) | 12.5 (11.5) |
| | 2 | 75 | 15 | 58.9 (54.3) | 26.7 (25.4) |

*1 gal = 3.785 L; 1975 dollars

**Numbers in parentheses indicate the costs of treatment after deducting the credit for methane produced at $1.50/1000 cu ft.

***After RO treatment, the total dissolved solids decreased to 300 mg/L and 60 mg/L for influent leachate BOD concentrations of 25000 mg/L and 5000 mg/L, respectively.

## 5 LESSONS LEARNED AT ARMY INSTALLATION SANITARY LANDFILLS

The previous discussion has dealt with lessons learned in the area of leachate recycle in both the private and public sectors. Development of landfill operation and maintenance techniques which most effectively treat the waste and simultaneously protect the environment is continually progressing. Thus, many of the techniques considered to be "state of the art" at the time of their adoption have proven to be faulty when implemented.

As a result, a number of problem landfills are threatening water supplies. Regardless of the Army's intentions when the landfills were initially constructed, the environmental community and the public view these landfills with extreme disapproval and are demanding corrective action. However, due to the evolving state of the art in landfill design and operation, it is often difficult to identify a clear-cut solution.

Using recycling to solve the leachate problem has met with opposition as problems with this technique have become apparent, particularly in older landfills that were not designed for leachate collection. The following sections describe several actions on Army installations related to landfill problem management. These descriptions are presented from a "lessons learned" viewpoint to assist other Army installations with landfill investigations. Most of the problems reported here have been investigated to determine the extent of the potential hazard; however, remedial plans have not yet been developed.

### Fort Dix, NJ

#### *Leachate Problem*

A sanitary landfill at Fort Dix operated from 1950 until it was closed in 1984. Until 1980, access to the landfill was not controlled, so waste disposal records are incomplete. However, it is known that a pit had been dug adjacent to the landfill to dispose of grease cleaned from mess hall traps, and it is suspected that chlorinated solvents were used to clean the grease traps. Futhermore, after access was controlled, drums of spent solvents were refused for burial. Therefore, it is very likely that solvents were buried there before access was controlled.

A Phase I, Installation Restoration Report published by Fort Dix in 1977 did not cover this landfill because it was not suspected of containing industrial waste. It was therefore not identified as a potential source of hazardous contaminants.

In 1982, the New Jersey Department of Environmental Protection (NJDEP) issued Fort Dix a permit for the landfill, but directed installation of 12 monitoring wells. Water samples taken from some of the wells were found to contain organic pollutants exceeding state standards on each of three successive test series. Those findings resulted in Fort Dix requesting the Army Environmental Hygiene Agency (AEHA) to study the problem comprehensively. Eight more monitoring wells were drilled; four of these were located to detect possible migration of organics off-post toward existing private wells. The results of subsequent testing and data analysis indicated that the probable source of the pollutants was the grease pit; however, conditions were not considered to seriously threaten the aquifer.

The NJDEP concluded otherwise, and elected to "nominate" the Fort Dix landfill for inclusion in the "National Priorities List" (a provision of Comprehensive Environmental Response, Compensation and Liability Act). At the request of Fort Dix, the U. S. Army Construction Engineering Research Laboratory (USA-CERL), in a cooperative effort with the U. S. Army Waterways Experiment Station (WES), examined the problem in depth.* This work involved drilling additional wells, sampling and testing water and leachate, conducting geophysical surveys, and measuring groundwater flow. The investigation concluded that there was groundwater contamination and that the most effective remedial action appeared to be capping the landfill in conjunction with installation of a hydrologic barrier to protect the aquifer, and excavating the grease pit areas. Additional investigations were also recommended.

The state had determined that the problem required more detailed investigation which should be performed in accordance with provisions of the National Oil and Hazardous Substances Pollution Contingency Plan (40 DFR 300). Therefore the NJDEP asked Fort Dix to enter into an Administrative Agreement to more clearly define the problem. A contract was then negotiated through the New York Corps of Engineers District and a contractor began the new investigation on 1 October 1985.

*Lessons Learned*

1. Consider old (closed) landfills to be hazardous waste disposal sites until thorough investigation proves otherwise.

2. Obtain the advice of technical experts available within the Army (e.g., USA-CERL, AEHA, and U. S. Army Toxic and Hazardous Materials Agency [USATHAMA]) whenever state regulatory authorities are considering unusually strict pollution abatement requirements. With early expert backup support, it may be possible to negotiate with the state on siting new landfills or on procedures to be followed in abating pollution from old (closed) landfills.

3. Obtain contractor assistance through the supporting Corps of Engineers District when in-house Army engineering and detailed technical assistance is not available to meet the time schedule imposed by state or local regulatory authorities.

4. Do not assume that the Army must fund all costs associated with landfill siting or corrective measures. For example, when negotiating a remedial plan with the state, the cost of off-post groundwater and surface water sampling and testing may be borne by the state or local government.

5. Develop detailed plans for any field investigations to be conducted on new landfill sites and or investigations of pollutants migrating from old (closed) landfill sites; coordinate these plans with appropriate state agencies before beginning work. This may prevent having to contract for supplemental investigations if state authorities find the data from initial investigations to be inadequate. However, procedural requirements are sometimes in the developmental state. In cases such as the one at Fort Dix, the requirements for site investigations were changing. In such instances, close coordination with state agencies is essential.

6. Employ the same basic approach described in Item 5 above when remedial construction is needed to correct a pollution problem and when a groundwater/surface

*In addition, a Landfill Task Force of personnel from interested agencies, including regulators and environmentalists, was assembled to guide the investigation.

water monitoring program is to be initiated. Early coordination with the state will often save time and money and help promote a trusting relationship.

7. Consider contract disposal of solid waste at an off-post landfill as an alternative to operating an on-post landfill.

**Fort Belvoir, VA**

*Leachate Migration Into Surface and Groundwaters*

A 21-acre sanitary landfill located in low ground adjacent to Accotink Creek on Fort Belvoir was closed in 1977 after 7 years of operation. Difficulties were encountered with groundwater and surface runoff collecting in the solid waste. This condition contributed to early closure of the site and construction of a new landfill on nearby higher ground. Before actual closure of the landfill, WES had conducted a site investigation. Results from monitoring wells determined that leachate had entered the groundwater and was migrating into Accotink Creek. However, the pollutants and their concentrations were not adversely impacting the environment. Consequently, no remedial action was considered necessary at that time.

Four years later, a study by an environmental engineering contractor verified that leachate was still being generated at an estimated 20,000 gpd (75 700 Lpd) and recommended closing the site. In 1979, another contracting firm evaluated leachate control measures for both the closed and active landfills. The following remedial measures were recommended:

1. Recapping the old landfill

2. Taking measures to intercept groundwater flow into the closed landfill by installing a 25-ft (7.5-m) gravel drain upslope from the site

3. Installing a 15-ft (4.5-m) bentonite slurry trench to prevent groundwater flow into Accotink Creek

4. Pumping leachate from sumps to be installed in the landfill into a lagoon and then recirculating the collected leachate onto the site.

Of these recommendations, action has been taken to recap the site and to perform routine groundwater monitoring.

The contractor also evaluated the active landfill, which had a problem with excessive ponding from surface runoff. Here, it was recommended that the drainage system be modified to divert as much water as possible from the working area and to pump collected water into Accotink Creek periodically. The drainage was revised, and instead of pumping collected water into the creek, a spray irrigation system was installed to dispose of the water in a nearby wooded area. This latter choice was made after consulting with state regulatory authorities as an alternative to obtaining a National Pollutant Discharge Elimination System (NPDES) permit for discharging into Accotink Creek.

*Lessons Learned*

1. Avoid siting a landfill in low-lying, water-saturated areas. Instead, conduct a detailed hydrogeologic investigation to select a site affording maximum protection to groundwater or surface water.

2. When a landfill is closed, install a proper cap to reduce leachate production.

3. Install and continuously maintain surface drainage structures on both closed and active landfills to divert run-on and prevent it from entering buried waste where it can produce leachate.

4. Do not recirculate leachate as a means of disposal; this only contributes to further leachate production, especially where buried wastes may already be saturated.

5. Conduct early consultation with state regulatory authorities to correct potential pollution problems.

6. Collect, treat, and dispose of leachate from old landfills only if the quantity and toxicity of the leachate is causing more than minimal harm to the environment. However, it is prudent to establish a continuing monitoring program and to coordinate any action with state or local regulatory authorities.

**Fort Drum, NY**

*Possible Groundwater Contamination*

Fort Drum has two landfills: one active and one inactive. The active site is located about 3000 ft (900 m) from the Army airfield in an area having mostly highly permeable sandy soil. The inactive landfill, which convers about 50 acres, is also located in poorly graded sand with high permeability. Debris scattered over much of the unvegetated surface was evidence of the old landfill, which was closed in 1973. Orange-colored, malodorous leachate was also observed seeping from the top of a fill embankment, which surfaces along a stream.

Fort Drum obtains all its water from 12 active wells within and near the cantonment area. Water quality tests of samples taken in 1969 revealed that all wells were producing high-quality water except one, which had excessive amounts of iron. Because of this condition and the proximity of the other pollution sources to the well field--such as a leaking fuel tank, numerous septic tanks and leaching fields, and a seepage pit--Fort Drum contracted with a consulting firm to install monitoring wells.

A subsequent on-site consultation by AEHA revealed the monitoring wells to be inadequate, both in number and depth. Several wells were drilled too shallow and were dry. This investigation resulted in the following recommendations for the landfills:

1. Cap the old landfill with an impermeable seal and vegetate the surface.

2. Control the leachate from the old landfill to prevent it from entering nearby streams.

3. Close the active landfill because it is too close to the airfield and is located in highly permeable soil.

4. Select a new landfill site in an environmentally acceptable location.

5. Install additional monitoring wells and actively survey groundwater to assess possible degradation in drinking water aquifers.

AEHA helped site and design a new landfill and prepared a permit application so that the installation could close the active landfill. This work involved extensive field investigation and soil analysis to find a site whose clay was sufficient to provide an acceptable liner. However, when the proposed landfill project was completed, it was disapproved because the site had been reserved for other purposes.

*Lessons Learned*

1. Consider contract disposal of solid waste when the installation's soil and subsurface geology do not provide the degree of groundwater protection required by state regulations.

2. Obtain the services of Army agencies having experts in hydrogeologic investigation to either develop groundwater monitoring programs or to independently evaluate plans before a construction contract is awarded.

3. Ensure that landfills are sited in accordance with USEPA and state regulations and that these facilities are properly reflected on the Installation Master Plan.

**Fort Belvoir, VA**

*Methane Gas Problem*

Because of the lack of detailed information on previously closed landfill sites on Fort Belvoir, the Directorate of Engineering and Housing examined available aerial photographs to locate former sites. One of the old landfills, which had been closed before 1960 and was thought to be in an uninhabited area, was actually adjacent to an elementary school.

A site visit revealed that differential settlement had occurred near the school and had resulted in cracks in the sidewalks and in paved playground areas. Furthermore, one long crack was observed along the building foundation. This raised suspicions that at least portions of the school were located over the old landfill, and that if landfill gas were present, the occupants could be in danger.

Shallow borings were made with a hand auger near the building foundation and readings were taken with a portable combustible gas meter. Initially, concentrations of methane as high as 40 percent were found near the building. WES then conducted an in-depth study to determine the gas concentration in the soil adjacent to the school and around nearby on-post housing areas, actual boundaries of the landfill; and the location of the local groundwater table.

To locate the landfill boundaries, augered holes were bored along the suspected edges of the landfill. For each boring, soil classification, depth to refuse, and water table were recorded. Gas measurements were taken as soon as the auger was removed from the boring. Borings were also made around the foundation to determine how much of the school was built on refuse.

Gas monitoring wells were installed between the landfill boundary and nearby on-post housing areas to determine the extent of off-site migration. Gas monitoring was also conducted in crawl spaces under housing units in one housing area and in the heating ductwork installed under the floors in another housing area. Fire department personnel conducted combustible gas surveys periodically until a continuous monitoring system was installed.

The results of the drilling program revealed the following:

1. A portion of the schoool had been built directly over 3 m of refuse.

2. Gas readings at the school were as high as 28 percent methane.

3. Monitoring wells installed to check gas migration toward housing areas revealed high initial methane levels.

Four alternatives to eliminate the gas problem were evaluated:

1. Excavate and rebury the landfill refuse.

2. Install an impermeable barrier trench (polyvinyl chloride [PVC] membrane and gravel backfill) along the landfill perimeter to prevent outward gas migration and remove the refuse under the school.

3. Install an active venting system (buried pipe with suction pumps) using extraction wells.

4. Install a blower and underground piping to keep gas from accumulating under the building.

The course of action taken was installation of a blower system to evacuate trapped gas under the building foundation and a continuous gas monitoring system. This alternative solved the problem effectively and was the least costly of the four choices. USA-CERL Technical Report N-173 provides additional details about this incident.[33]

*Lessons Learned*

1. Do not construct buildings on top of or close to a closed landfill until methane gas production has stopped.

2. Note that explosive concentrations of methane gas can migrate a considerable distance from a landfill when coarse-grained soils are present.

3. Conduct periodic on-the-ground inspections of old landfill sites and adjacent areas for evidence of methane gas.

[33] R. A. Shaffer, et al., *Landfill Gas Control at Military Installations*, Technical Report N-173/ADA140190 (USA-CERL, 1984).

## 6 CONCLUSIONS AND RECOMMENDATIONS

Recycle of leachate through a sanitary landfill offers several advantages. It provides a mechanism for increasing the stabilization rate of biodegradable organic matter within the landfill with respect to methane formation. This will likely allow the more rapid, less restrictive reuse of the area after the landfill is closed. Recycle also offers a potential method for partial treatment of leachate, such as removal of some heavy metals and organic compounds. There is little information about the capability of leachate recycle to remove priority pollutants.

However, while recycling appears to decrease the concentrations of some contaminants in leachate, it does not provide sufficient treatment to allow discharge of the recycled leachate to surface- or groundwaters without further treatment. Recycle has been used as a method of leachate disposal, and is effective to the extent that evapotranspiration can occur. However, recycling also increases the likelihood of groundwater contamination because of the increased amount of water within the landfill. It also may increase the possibility of surface water contamination by runoff of applied leachate. Chemical contaminants in the leachate may be chronically toxic to aquatic organisms or cause cancer in humans. Also some of these contaminants may be hazardous at levels that current technology cannot yet reliably measure. Thus, recycling is only appropriate under highly controlled conditions.

Appropriate designs for leachate recycling should include the following: optimal site selection (i.e., the landfill should not have high groundwater or unstable soil slopes); a liner that is resistant to puncture and has a permeability appropriate to use with leachate; adequate drainage; a gas recovery system; and provisions for post-recycle leachate treatment.

Examination of case histories provided information about many site-specific problems with leachate recycle. However, three themes tended to occur at all the sites, and the lessons learned can be applied to future decisions about use of leachate recycle.

First, coordinate investigations closely with all regulatory agencies involved, and seek out all parties who have an interest in regulating or overseeing the landfill. Since technology and policies in the area of landfill control and design are constantly evolving, the requirements of one agency may not be as stringent as those of another. By gathering all interested parties into the investigation, such as Fort Dix did by establishing the Landfill Task Force, a consensus of all agencies can be obtained to guide the investigation. It is also important to identify early in the investigation which agency (i.e., local, state, or Federal) will take the lead in overseeing the investigation.

Second, it is important to use the technical expertise available from Army agencies such as AEHA, USA-CERL, and USATHAMA to assist with the investigation. These agencies can help plan the development, execution, and presentation of results.

Finally, since groundwater contamination is becoming an emotional issue to the public, it is important to present results of any investigations to both the regulatory agencies and the press and to maintain good communication with all interested parties. Installations must show that landfills were operated within the constraints of the law when they were constructed, and that the Army is actively pursuing solutions to any problems that may have arisen.

It is recommended that leachate recycle be evaluated on a case-by-case basis in terms of the potential benefits it can provide to each particular landfill system, and the importance of those benefits. At most Army installations, the lack of leachate collection/containment systems will preclude the use of this technique, particularly at older or closed landfills. Therefore, it is recommended that leachate recycle be practiced only at new, properly designed sites having leachate collection systems that will prevent groundwater contamination. Before considering such a system, local or state regulations should be investigated to determine if recycle is permitted. The system should be constructed with appropriately placed monitoring wells in the surrounding saturated and unsaturated groundwater. These wells should be monitored indefinitely to detect leachate migration before it reaches usable groundwater. A program should be planned for remedying problems that would occur if the system fails and contaminants begin to migrate from the system.

A post-recycle treatment system should be incorporated into a leachate recycling plan to remove heavy metals and organics that could adversely affect surface- or groundwater quality after discharge.

The continuous evolution of environmental regulations requires the Army to keep abreast of new developments. In the future, regulatory agencies may change the focus of concern from general water characteristics such as BOD and COD to specific compounds such as priority pollutants. Thus, Army installations should be adaptable and ready to meet or exceed new requirements as they arise.

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